8-AE

INTEGRITY OF DIVERTER SYSTEMS UNDER ABRASIVE, MULTI-PHASE FLOW

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Objective: To enhance design criteria for blowout prevention systems used to handle sand cut produced from shallow gas formations.

Safety of personnel, equipment and environment is a concern in offshore hydrocarbons explorations. Blowouts are among the most dangerous hazards in marine environments where abnormal formation pressures may be encountered at very shallow depths. Well control is especially difficult where a threatened blowout situation occurs prior to setting surface casing in the well. If the conventional blowout prevention equipment and procedures are applied, hydraulic fracturing is likely to occur in an exposed shallow formation due to the pressure build-up in the well. Moreover, if one or more fractures reach the surface, the resulting flow can destroy the foundations of a bottom supported structure.

Presently, the best available procedure for handling a threatened blowout from a shallow gas formation is to divert the gas flow away from the rig structure and drilling personnel. This requires the use of a diverter system large enough to prevent a pressure build-up within the well bore, minimizing exposure of the weakest formation to fracture. Figure 1 exhibits the key parts of a diverter system. The essential elements of a diverter system include:

(1) a vent line for conducting the flow away from the structure,
(2) means for closing the well annulus above the vent line during diverter operations, and
(3) means for closing the vent line during normal drilling operations.

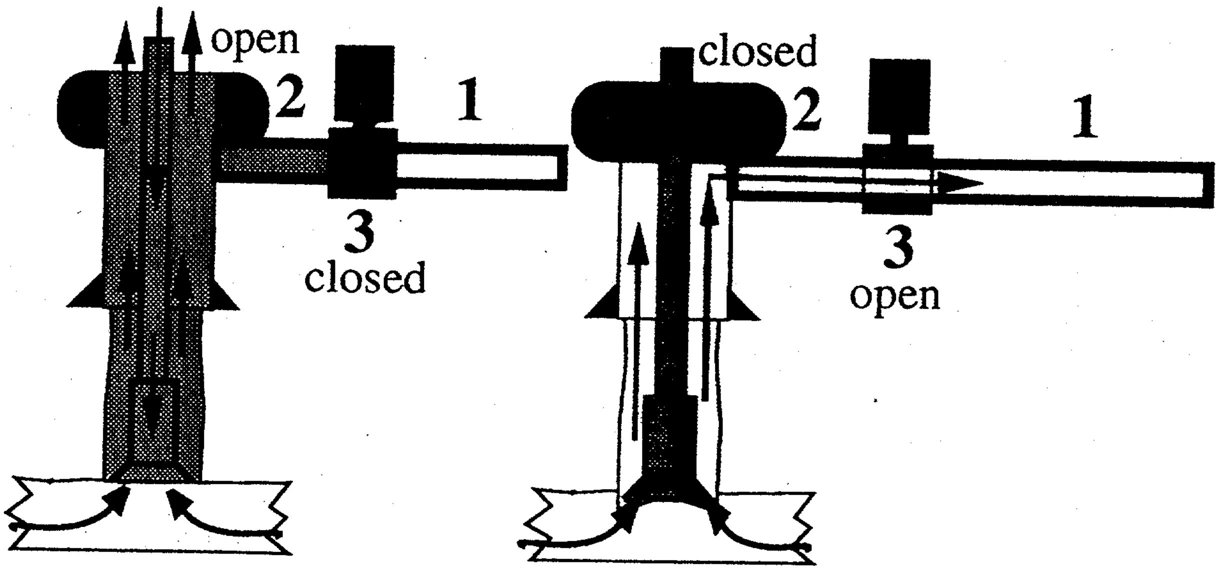
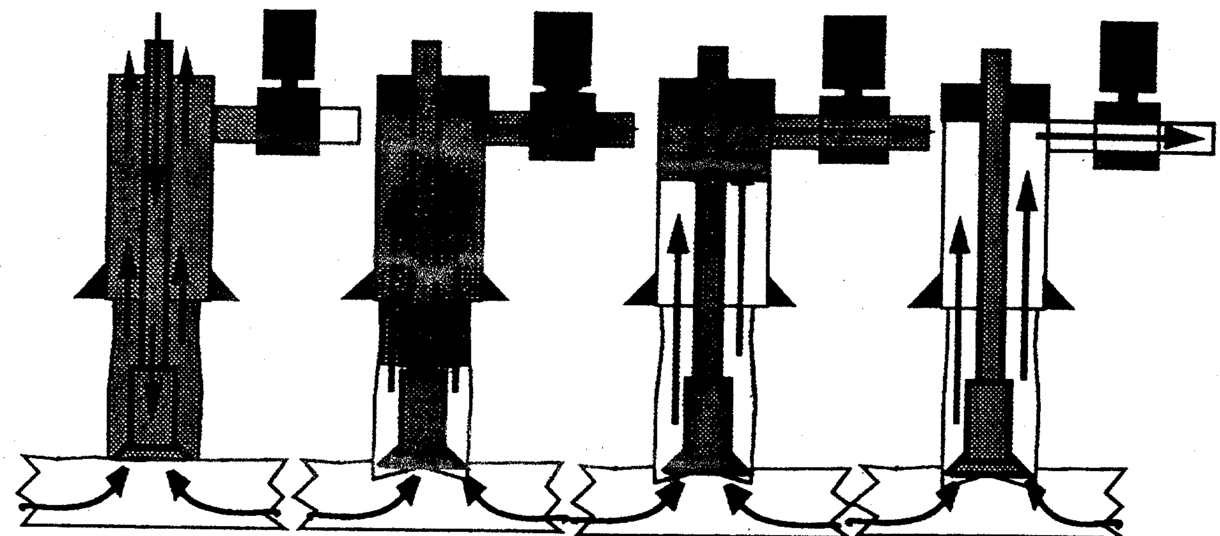


Figure 1. **Schematic of the main components of a diverter system**

The sequence of events occurring when a shallow gas flow is encountered are illustrated in Figure 2. When the driller recognizes that the well has begun to flow, the diverter system is actuated (1b). This simultaneously causes the vent line to open and the annular diverter head to close. As drilling fluid is displaced from the well, the rate of gas flow into the well increases due to the loss in bottom-hole pressure (1c). After the well is unloaded of drilling fluid, a semi-steady state condition is reached (1d) in which formation gas, water, and sand are flowing through the vent line.



(a) Normal flow path. (b) Diverter system activated. (c) Unloading the well. (d) Pseudo-steady state flow.

Figure 2. Events during operations with a diverter system.

Although conceptually simple, the design, maintenance, and operation of an effective diverter system for the various types of drilling vessels is a difficult problem. Past experience has shown that when a situation calling for the use of a diverter arises, failure in the diverter system often occurs. Among other factors, failures generally result from erosion of its component parts. Erosion occurs predominantly in the fittings where the flow changes direction. Even if every part of a diverter system functioned properly, the erosive nature of the solids in the flow stream could severely limit the vent line life.

Experimental Equipment and Procedure

This work focused on obtaining erosion factors for short and long radius elbows, made of carbon steel. These erosion factors should be useful for predicting the life of diverter systems under multiphase flow. In a previous study, erosion rates of various fittings were measured for mud-sand slurries and gas-water-sand mixtures in pipes of 2-in. internal diameter. Based in this previous work, a predictive model was developed and published (see Appendix A). In this study erosion rate of fittings were measured for gas-water-sand mixtures in pipes of 6-in. internal diameter. These data were then used to test the accuracy of the predictive model when extrapolated to longer pipe sizes. Now MMS requires a minimum inside diameter of 10-in. for diverter systems. It was felt that data for a 6" size system will help validate extrapolation to large diameters. Equipment limitations precluded to work with a full size 10-in. system.

Two basic models of diverter systems were constructed at the LSU/MMS Research Well Facility in order to perform these experiments; one of them was used for mud-sand slurries; the other two were used for gas-water-sand mixtures. A schematic of a model used for gas-water -sand mixtures is shown in Figure 3.

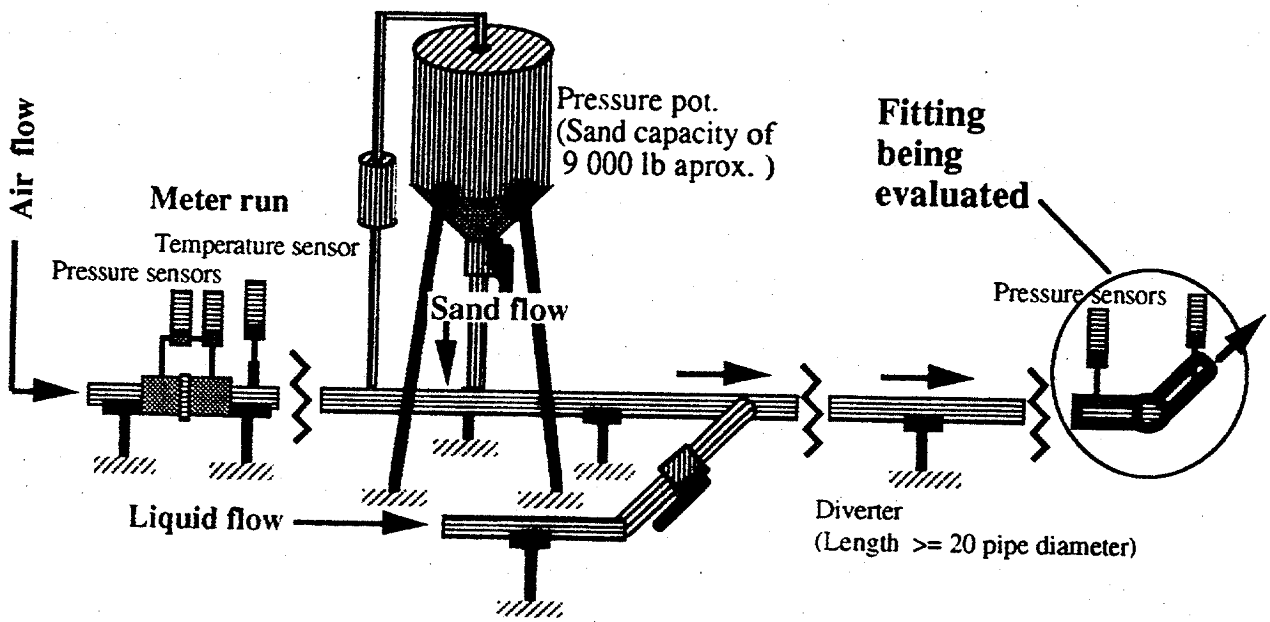


Figure 3. Schematic of a model diverter system for erosion tests.

The experimental equipment consisted of five modules; (1) a meter run to monitor the air flow rate; (2) a pressure pot and piping required to provide the abrasive mass rate; (3) a pipe and valve to inject water; (4) a diverter pipe; (5) a fitting connected to the exit of the diverter pipe to provide a change on flow direction.

The fluids used in this experiment were tap water and air. Air, for the runs in 6.0-in. nominal diameter,was supplied by three compressors connected in parallel. The sand used as the abrasive material for these tests was No. 2 blasting sand.

The test procedure was as follows: Air from a compressor was routed throughout the metering station (Meter run); once the desired range of steady state gas flow rate was obtained, a fixed water flow rate was injected by a triplex pump into the upstream side of the diverter section. As soon as the fluid flow rates were stabilized, sand from the pressure pot was injected at a predetermined mass flow rate, and simultaneously the data acquisition process was started.

Data on air flow rate, air exit pressure, water flow rate, and sand mass rate were recorded as a function of time. Usually, data collection continued up to failure of the fitting being evaluated.

Summary

The experimental data obtained provided valuable insight into the erosion rates occurring in the complex multiphase flow behaviour of well/diverter systems at sonic and near sonic velocities. In the past, erosion studies using flat plates [1,2,3] have shown that the mass of material abraded from a solid surface is proportional to the mass of abrasives striking the solid surface. Therefore a specific erosion factor, F_e, is often used to express the erosion caused by particle impact; this specific erosion factor is defined as the mass of steel removed per unit of mass of abrasive. Also, previous studies found erosion rate to be dependent on the impact angle [3] of the solid particles with the eroding surface.

Bourgoyne [4] measured the specific erosion rate, F_e, of various fittings. The fittings evaluated included steel elbows, plugged tees, vortice elbows, and rubber hoses. He proposed the following equations for estimating the rate of loss in wall thickness.

Rate of Loss in Wall Thickness.

Dry Gas or Mist. The loss in thickness, h_w, with time, t, of a fitting in a diverter system where dry gas or mist is the continuous phase is given by the following expression in SI units:

$$\frac{dh_w}{dt} = F_e \frac{\rho_a}{\rho_s} \frac{q_a}{A} \left(\frac{u_{sg}}{100\,\lambda_g} \right)^2 \qquad (1)$$

Liquid. The loss in thickness, h_w, with time, t, of a fitting in a diverter system where liquid is the continuous phase is given by the following expression in SI units:

$$\frac{dh_w}{dt} = F_e \frac{\rho_a}{\rho_s} \frac{q_a}{A} \left(\frac{u_{sl}}{100\,\lambda_l} \right)^2 \qquad (2)$$

where F_e is the specific erosion factor, ρ_s is the density of the diverter system's component, ρ_a is the density of abrasive material, A is the cross sectional area of the diverter system's component, q_a is the abrasive volumetric flow rate, u_{sg} is the superficial gas velocity, u_{sl} is the superficial liquid velocity, λ denotes the volume fraction (hold-up) and subscripts g, and l denotes the gas, and liquid phases present.

Bourgoyne [4] recommended values for specific erosion factors, Fe. These values are presented in Table 1, and are based in an average superficial gas velocity of 100 m/s in a 2-in. internal diameter diverter system. Data for slurries of mud and sand are not included in this report; specific erosion factors for mixtures of sand and mud were small compared with that of mixtures of sand and air. In fact, erosion factors for mud carried abrasives were smaller by one to two orders of magnitude [4].

Table 1

Recommended Values of Specific Erosion Factor (After Bourgoyne 4)

Fitting type	Curvature radius r/d	Material	Grade	Specific Erosion Factor g/kg			
				Dry gas flow		Mist flow	
Elbow	1.5	Cast steel	WBC	2.2		2.8	
		Seamless steel	WPB		0.89		1.1
	2.0	Cast steel	WBC	2.0		2.4	
		Seamless steel	WPB		0.79		0.93
	2.5	Cast steel	WBC	1.7		2.0	
		Seamless steel	WPB		0.69		0.77
	3.0	Cast steel	WBC	1.5		1.65	
		Seamless steel	WPB		0.60		0.66
	3.5	Cast steel	WBC	1.2		1.32	
		Seamless steel	WPB		0.52		0.55
	4.0	Cast steel	WBC	0.9		1.0	
		Seamless steel	WPB		0.45		0.49
	4.5	Cast steel	WBC	0.7		0.77	
		Seamless steel	WPB		0.40		0.44
	5.0	Cast steel	WBC	0.5		0.55	
		Seamless steel	WPB		0.35		0.38
Flexible hose	6.0	Rubber	-----	1.00		1.22	
	8.0	Rubber	-----	0.40		0.45	
	10.0	Rubber	-----	0.37		0.39	
	12.0	Rubber	-----	0.33		0.35	
	15.0	Rubber	-----	0.29		0.31	
	20.0	Rubber	-----	0.25		0.28	
Plugged tee	—	Cast steel	WBC	0.026		0.064	
	—	Seamless steel	WPB		0.012		0.040
Vortice elbow	3.0	Cast steel	WBC	0.0078*			

* *Assumes failure in pipe wall downstream of bend*

The values presented in this table gave an average error of 29% which was felt to be acceptable for designing diverter systems. The error was based on the collected experimental data.

Verification for 6-in. Diameter.

Shown in Table 2 is a comparison of the measured erosion rates in the larger pipe size with those predicted by Equation (1). Note that the average error for these runs was 26%. These experimental data cover air and mist flow for the long, 1.5, curvature radius elbow.

Table 2

Comparison of Calculated and Measured Erosion Rates in 6-in.Diameter Diverter Systems

					Erosion Rate		
R/d -	Usl m/s	Usg m/s	Sand Rate m^3/s	Fe kg/kg	Calculated m/s	Actual m/s	Error -
1	0	30.9	432E-6	0.0021	2E-6	741E-9	112%
1	0	66.38	508E-6	0.0021	9E-6	8E-6	13%
1	0	76.59	509E-6	0.0021	11E-6	10E-6	19%
1	0	76.99	407E-6	0.0021	9E-6	8E-6	22%
1	0	77.68	273E-6	0.0021	6E-6	5E-6	38%
1	0	97.67	485E-6	0.0021	18E-6	16E-6	13%
1.5	0	59.44	807E-6	0.0014	7E-6	9E-6	-18%
1.5	0	61.68	352E-6	0.0014	3E-6	4E-6	-15%
1.5	0	98.43	578E-6	0.0014	14E-6	28E-6	-49%
1.5	0	99.39	844E-6	0.0014	21E-6	32E-6	-34%
1.5	0	101.7	128E-6	0.0014	3E-6	6E-6	-46%
1.5	0	103.2	328E-6	0.0014	9E-6	15E-6	-39%
1.5	0.00376	68.58	448E-6	0.0017	6E-6	7E-6	-10%
1.5	0.0125	68.7	470E-6	0.0017	7E-6	7E-6	3%
1.5	0.2274	88.15	717E-6	0.0017	17E-6	15E-6	16%
1.5	0.0125	100.8	497E-6	0.0017	16E-6	15E-6	7%
1.5	0.00376	101.49	516E-6	0.0017	16E-6	15E-6	10%

Seamless steel elbows, Grade WPB.

Combination of the new and old data yields slightly different average values for specific erosion rate factors. These modified recommended values are given in Table 3. A comparison of the observed and predicted values of erosion rate using these specific erosion rate factors are shown in Table 4. Note that the average error for all of the data is about 40 %. The same value is obtained by using the values presented in Table 1. However , the values recommended in table 3 yield better prediction for the larger diameters.

Table 3

Recommended Values of Specific Erosion Factor Based on 2-in. and 6-in. Diameter Diverter Systems

FITTING TYPE	CURVATURE RADIUS r/d	MATERIAL	GRADE	SPECIFIC EROSION FACTOR g/kg			
				DRY GAS FLOW		MIST FLOW	
ELBOW	1.0	Cast steel	WBC				
		Seamless steel	WPB		2.1		
	1.5	Cast steel	WBC	2.2		2.8	
		Seamless steel	WPB		1.4		1.7
	2.0	Cast steel	WBC	2.0		2.4	
		Seamless steel	WPB		0.79		0.93
	2.5	Cast steel	WBC	1.7		2.0	
		Seamless steel	WPB		0.69		0.77
	3.0	Cast steel	WBC	1.5		1.65	
		Seamless steel	WPB		0.60		0.66
	3.5	Cast steel	WBC	1.2		1.32	
		Seamless steel	WPB		0.52		0.55
	4.0	Cast steel	WBC	0.9		1.0	
		Seamless steel	WPB		0.45		0.49
	4.5	Cast steel	WBC	0.7		0.77	
		Seamless steel	WPB		0.40		0.44
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FLEXIBLE HOSE	6.0	Rubber	-----	1.00		1.22	
	8.0	Rubber	-----	0.40		0.45	
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	12.0	Rubber	-----	0.33		0.35	
	15.0	Rubber	-----	0.29		0.31	
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PLUGGED TEE	—	Cast steel	WBC	0.026		0.064	
	—	Seamless steel	WPB		0.012		0.040
VORTICE ELBOW	3.0	Cast steel	WBC	0.0078*			

* *Assumes failure in pipe wall downstream of bend*

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Comparison of Calculated and Measured Erosion Rates on 2-in. and 6-in.Diameter Diverter Systems

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1	0	97.67	485E-6	0.0021	18E-6	16E-6	13%
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1.5	0	61.68	352E-6	0.0014	3E-6	4E-6	-15%
1.5	0	98.43	578E-6	0.0014	14E-6	28E-6	-49%
1.5	0	99.39	844E-6	0.0014	21E-6	32E-6	-34%
1.5	0	101.7	128E-6	0.0014	3E-6	6E-6	-46%
1.5	0	103.2	328E-6	0.0014	9E-6	15E-6	-39%
1.5	0.003761	68.58	448E-6	0.0017	6E-6	7E-6	-10%
1.5	0.0125	68.7	470E-6	0.0017	7E-6	7E-6	3%
1.5	0.2274	88.15	717E-6	0.0017	17E-6	15E-6	16%
1.5	0.0125	100.8	497E-6	0.0017	16E-6	15E-6	7%
1.5	0.003761	101.49	516E-6	0.0017	16E-6	15E-6	10%
1.5	0	32	17E-6	0.0014	409E-9	374E-9	9%
1.5	0	47	26E-6	0.0014	1E-6	332E-9	294%
1.5	0	72	45E-6	0.0014	5E-6	2E-6	229%
1.5	0	93	49E-6	0.0014	10E-6	4E-6	167%
1.5	0	98	45E-6	0.0014	10E-6	4E-6	137%
1.5	0	98	53E-6	0.0014	12E-6	5E-6	141%
1.5	0	103	53E-6	0.0014	13E-6	5E-6	148%
1.5	0	122	60E-6	0.0014	21E-6	34E-6	-39%
1.5	0	167	77E-6	0.0014	51E-6	37E-6	35%
1.5	0	169	94E-6	0.0014	63E-6	48E-6	32%
1.5	0	177	132E-6	0.0014	96E-6	83E-6	15%
1.5	0	177	110E-6	0.0014	81E-6	74E-6	10%
1.5	0	178	109E-6	0.0014	81E-6	65E-6	24%
1.5	0	203	112E-6	0.0014	108E-6	78E-6	39%
1.5	0	205	144E-6	0.0014	142E-6	80E-6	78%
1.5	0	222	114E-6	0.0014	131E-6	70E-6	87%
1.5	0	108	19E-6	0.0014	5E-6	4E-6	44%
1.5	0	109	35E-6	0.0014	10E-6	6E-6	72%
1.5	0	108	36E-6	0.0014	10E-6	5E-6	86%
1.5	0	104	58E-6	0.0014	14E-6	10E-6	46%
1.5	0	108	65E-6	0.0014	18E-6	14E-6	27%
1.5	0	108	75E-6	0.0014	21E-6	14E-6	56%
1.5	0	107	112E-6	0.0014	30E-6	14E-6	109%
1.5	0	111	145E-6	0.0014	41E-6	22E-6	85%
1.5	0	107	227E-6	0.0014	60E-6	36E-6	70%
1.5	0	106	240E-6	0.0014	63E-6	33E-6	93%
1.5	0	103	282E-6	0.0014	69E-6	30E-6	134%

Seamless steel elbows, Grade WPB

Conclusions

The study of multiphase flow trough diverters shows, in general, that the erosion rate for fluids containing abrasive solids:

(1) Increases exponentially with the fluid flow rate for a given sand rate.

(2) Increases linearly with sand flow rate for a given fluid flow rate.

Also, updated and extended specific erosion factors required to estimate erosion rates are presented in this work.

Acknowledgement

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Nomenclature

A - Cross sectional area, m.
d - Diameter, m.
F - Specific factor, kg/kg.
h - Thickness, m.
q - Flow rate, m^3/s.
R - Curvature radius, m.
u - Velocity, m/s.
λ - Fractional volume or holdup.
ρ - Density, kg/m^3

Subscripts

a - Abrasives.
e - Erosion.
g - Gas.
l - Liquid.
m - mixture.
s - Steel,or superficial.
w - Wall.

APENDIX A

SPE/IADC 18 716

EXPERIMENTAL STUDY

OF

EROSION IN DIVERTER SYSTEMS DUE TO SAND PRODUCTION